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PATENT SPECIFICATION

619,722



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PROVISIONAL SPECIFICATION

Improvements in and relating to Boundary Layer Control in Fluid Conduits

EXAMINER'S
Div. 1

We, THE ENGLISH ELECTRIC COMPANY LIMITED, a Company registered under British Law, of Queen's House, 28, Kingsway, London, W.C.2, and LESLIE JACK CHESHIRE, a British Subject, of Willans Works, Rugby, do hereby declare the nature of this invention to be as follows:—

The invention relates to boundary layer control in fluid conduits, and particularly to those used in, or in connection with, elastic fluid machines.

It is well known that where the static pressure of a fluid increases in the direction of flow, (hereinafter called adverse pressure gradient) the thickness of the layer of slow moving fluid at a boundary tends to increase, and in limiting cases the main body of the fluid may leave the surface entirely. These effects, directly or indirectly, cause a serious loss of total pressure in fluid conduits, particularly in bends and curves, or in compressors in which there is inherently an adverse pressure gradient.

The provision of "bleeding" slots or holes at relevant positions through which the boundary layer fluid is drawn off is known in some cases to effect a great improvement in maintaining a thin boundary layer and an efficient flow. Such slots or holes, however, require such a degree of precision in proportioning and placing that they are often in practice ineffective. As they affect the normal shape of the surface they may themselves cause disturbances of the flow.

The invention is concerned with means for drawing off the boundary layer fluid from the regions of adverse pressure gradient without affecting the shape of the surface, and makes use of a porous insert or inserts which may form part of a stationary conduit or of the stationary and/or rotary elements of a machine such as a rotary compressor.

The porous insert may consist of a sintered metal or alloy, or of a ceramic

mass, or of closely packed fine mesh metal gauze; its surface conforms with that of the element wherein it is arranged.

In order to be better understood and readily carried into effect, the invention is hereinafter described with reference to the accompanying drawings of which:—

Fig. 1 shows a diagrammatic part view of an axial flow compressor in longitudinal section,

Fig. 2 is a longitudinal section through the impeller and diffuser on a double entry centrifugal compressor;

Fig. 3 is a part view in section through the diffuser vanes of a centrifugal compressor;

Fig. 4 is a section through vanes which may be used as stationary guide vanes of a cascade of a ducting system or as blades of a stationary or rotating blade ring of a turbine or compressor;

Fig. 5 is a modified detail of Fig. 1; and Fig. 6 is a cross section through a pair of consecutive vanes of a similar kind.

Referring first to Fig. 1, the casing or stator 1 of an axial flow compressor comprises a number of stationary vane rings 1a to 1d, and the rotor 2 comprises corresponding rings of rotary blades 2a to 2e.

Between adjacent rings of stator vanes, or at least some of them, such as 1c and 1d, there is a porous insert 3 occupying the whole or part of the circumference and connected by a pipe 4 to a zone of lower pressure, which may be the outer atmosphere.

Preferably the fluid drawn off at 3 is fed back into the system at a zone of lower pressure such as a lower stage of the compressor, say through a pipe 6 and a duct 7 issuing between the ring of rotor blades 2b and stator vanes 1b as shown or preferably immediately in front of the ring of rotor blades.

According to the alternatives shown in Figs. 5 and 6 the tapped-off fluid is fed back through the trailing edges of stator vanes 27, for example by making these

[Price 2/-]

vanes hollow (Fig. 6) or providing a bore 28 in them (Fig. 5) and providing outlets 29 over part or the whole of their trailing edges (Figs. 5 or 6 respectively). A plurality of ducts 7 may communicate with an annular cavity 7a in the casing 1. Alternatively the drawn-off fluid may be fed into a lower pressure zone of an associated machine, such as another compressor in series flow arrangement.

It is particularly advantageous to align the ducts 7 in relation to the axis so that the fluid issuing from them has a component in the direction of the general flow of fluid. Cooling of the drawn-off fluid in a cooler 5 arranged between the tapping-off zone 3 and the return duct 7 to the system is of further advantage.

Likewise, porous inserts 8 may be provided between all or some adjacent rows of rotor blades such as shown between ring 2c and 2d. The boundary fluid is drawn off through the duct 9 and a central bore 10 in the rotor 2 and dealt with in a similar way as described with reference to the stator, i.e. it may be ducted directly to some previous rotor stage. The direction of the ducts where the fluid re-emerges into the bladed zone conforming as far as possible to the general direction of flow relative to the rotor. This may be accomplished by the use of hollow blades through which the fluid is fed radially and from which it emerges through slots in the trailing edge, similar to feeding back through the hollow stator vanes as shown in Figs. 5 or 6.

Referring now to Fig. 2, the central or hub portion of a centrifugal impeller is denoted 11, a double entry impeller having vanes 12a, 12b being assumed in Fig. 2. However, the invention is applicable also to single entry centrifugal impellers. The stator or casing 13 has, in the zone of the biggest adverse pressure gradient of the impeller, pockets 14 partly filled with porous inserts 15. These pockets which may occupy the whole or part of the circumference are connected with a zone of lower pressure substantially as

described with reference to Fig. 1. The tapped-off fluid may then be fed back in a substantially tangential direction at a radius at which the total pressure relative to the casing is equal to, or below that of, the tapped-off fluid.

The vortex chamber 16 may be similarly equipped with porous inserts 17a, 17b on either side, or on one side only. In the bend 18 a cascade of vanes may be arranged as shown in, and described more in detail with reference to, Fig. 4. Similarly, porous inserts 20 may be arranged in the diffuser 19, all these inserts being connected with a low pressure zone substantially as described.

Alternatively or additionally to the porous inserts 17a, 17b, the diffuser vanes 21 (if any) in the stator outside the impeller may be equipped with porous inserts 22 (Fig. 3) the back of which is connected by transverse ducts 23 to a zone of lower pressure substantially as described.

Referring now to Fig. 4, the vanes 24 are equipped with porous inserts 25 tapped-off by transverse bores 26. Such vanes may be inserted in an appropriate position within the bend 18 of Fig. 2 or in any other cascade bend, the arrow A indicating the direction of flow. Fig. 4 may, however, be interpreted as illustrating the cross section through two consecutive blades of a ring of blades, such as used in the stator and/or rotor of an axial flow compressor, in which case arrow B is indicating the circumferential direction. This use of the porous inserts for the control of the boundary layer allows much higher aerodynamic loading of the blades without thickening or separation of the boundary layer.

Although the invention is primarily concerned with elastic fluids, it is applicable also to liquids and when similar effects of increasing thickness of boundary layer occur with them.

Dated this 11th day of December, 1946.

L. B. SHUFFREY,
Agent for the Applicants.

COMPLETE SPECIFICATION

Improvements in and relating to Boundary Layer Control in Fluid Conduits

We, THE ENGLISH ELECTRIC COMPANY LIMITED, a Company registered under British Law, of Queen's House, 28, Kingsway, London, W.C.2, and LESLIE JACK CHESHIRE, a British Subject, of Willans Works, Rugby, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention relates to boundary layer control in fluid conduits used in, or in connection with, fluid machines in general, and elastic fluid machines in particular.

It is well known that where the static pressure of a fluid increases in the direction of flow, (hereinafter called adverse pressure gradient) the thickness of the layer of slow moving fluid at a boundary

tends to increase, and in limiting cases the main body of the fluid may leave the surface entirely. These effects, directly or indirectly, cause a serious loss of total pressure in fluid conduits, particularly in bends and curves, or in compressors in which there is inherently an adverse pressure gradient.

The provision of "bleeding" slots or holes at relevant positions through which the boundary layer fluid is drawn off is known in some cases to effect a great improvement in maintaining a thin boundary layer and an efficient flow. Such slots or holes, however, require such a degree of precision in proportioning and placing that they are often in practice ineffective. As they affect the normal shape of the surface they may themselves cause disturbances of the flow.

The invention is concerned with means for drawing off the boundary layer fluid from regions of adverse pressure gradient of a conduit without affecting the shape of the surface, and makes use of a porous insert or inserts which may form part of a stationary conduit or of the stationary and/or rotary elements of a machine such as a rotary compressor.

The porous insert may consist of any porous material such as a sintered metal or alloy, or of a ceramic mass, or of closely packed fine mesh metal gauze, its surface conforming with that of the element wherein it is arranged.

In order to be better understood and readily carried into effect, the invention is hereinafter described with reference to the drawings left with the provisional specification, of which:—

Fig. 1 shows a diagrammatic part view of an axial flow compressor in longitudinal section;

Fig. 2 is a longitudinal section through the impeller and diffuser of a double entry centrifugal compressor;

Fig. 3 is a part view in section through the diffuser vanes of a centrifugal compressor;

Fig. 4 is a section through vanes which may be used as stationary guide vanes of a cascade of a ducting system or as blades of a stationary or rotating blade ring of a turbine or compressor;

Fig. 5 is a modified detail of Fig. 1; and

Fig. 6 is a cross section through a pair of consecutive vanes of a similar kind.

Referring first to Fig. 1, the casing or stator 1 of an axial flow compressor comprises a number of stationary vane rings 1a to 1d, and the rotor 2 comprises corresponding rings of rotary blades 2a to 2e.

Between adjacent rings of stator vanes, or at least some of them, such as 1c and

1d, there is a porous insert 3 occupying the whole or part of the circumference and connected by a pipe 4 to a zone of lower pressure, which may be the outer atmosphere.

Preferably the fluid drawn off at 3 is fed back into the system at a zone of lower pressure such as a lower stage of the compressor, say through a pipe 6 and a duct 7 issuing between the ring of rotor blades 2b and stator vanes 1b as shown or preferably immediately in front of the ring of rotor blades.

According to the alternative shown in Figs. 5 and 6 the tapped-off fluid is fed back through the trailing edges of stator vanes 27, for example by making these vanes hollow (Fig. 6) or providing a bore 28 in them (Fig. 5) and providing outlets 29 over part or whole of their trailing edges (Fig. 5 or 6 respectively). A plurality of ducts 7 may communicate with an annular cavity 7a in the casing 1. Alternatively the drawn-off fluid may be fed into a lower pressure zone of an associated machine, such as another compressor in series flow arrangement.

It is particularly advantageous to align the ducts 7 in relation to the axis so that the fluid issuing from them has a component in the direction of the general flow of fluid. Cooling of the drawn-off fluid in a cooler 5 arranged between the tapping-off zone 3 and the return duct 6 to the system is of further advantage.

Likewise, porous inserts 8 may be provided between all or some adjacent rows of rotor blades such as shown between ring 2c and 2d. The boundary fluid is drawn off through the duct 9 and a central bore 10 in the rotor 2 and dealt with in a similar way as described with reference to the stator, i.e. it may be ducted directly to some previous rotor stage, the direction of the ducts where the fluid re-emerges into the bladed zone conforming as far as possible to the general direction of flow relative to the rotor. This may be accomplished by the use of hollow blades through which the fluid is fed radially and from which it emerges through slots in the trailing edge, similar to the feeding back through the hollow stator vanes as shown in Figs. 5 or 6.

Referring now to Fig. 2, the central or hub portion of a centrifugal impeller is denoted 11, a double entry impeller having vanes 12a, 12b being assumed in Fig. 2. However, the invention is applicable also to single entry centrifugal impellers. The stator or casing 13 has, in the zone of the biggest adverse pressure gradient of the impeller, pockets 14 partly filled with porous inserts 15. These pockets which may occupy the whole or part

of the circumference are connected with a zone of lower pressure substantially as described with reference to Fig. 1. The tapped-off fluid may then
 5 be fed back in a substantially tangential direction at a radius at which the total pressure relative to the casing is equal to, or below that of, the tapped-off fluid.

10 The vortex chamber 16 may be similarly equipped with porous inserts 17a, 17b on both sides, or on one side only. In the bend 18 a cascade of vanes may be arranged as shown in, and described more
 15 in detail with reference to, Fig. 4. Similarly, porous inserts 20 may be arranged in the diffuser 19, all these inserts being connected with a low pressure zone or zones substantially as described.

Alternatively or additionally to the porous inserts 17a, 17b, the diffuser vanes 21 (if any) in the stator outside the impeller may be equipped with porous
 25 inserts 22 (Fig. 3) the back of which is connected by transverse ducts 23 to a zone of lower pressure substantially as described.

Referring now to Fig. 4, the vanes 24
 30 are equipped with porous inserts 25 tapped-off by transverse bores 26. Such vanes may be inserted in an appropriate position within the bend 18 of Fig. 2 or in any other cascade bend, the arrow A indicating the direction of flow. Fig. 4 may, however, be interpreted as illustrating the cross section through two consecutive blades of a ring of blades, such as used in the stator and/or rotor of an axial
 40 flow turbine or compressor, in which case arrow B is indicating the circumferential direction. This use of the porous inserts for the control of the boundary layer allows much higher aerodynamic loading
 45 of the blades without thickening or separation of the boundary layer.

Although the invention is primarily concerned with elastic fluids, it is applicable also to liquids and when similar
 50 effects of increasing thickness of boundary layer occur with them.

We are aware of the fact that porous surface sections have been proposed for the drawing-off of boundary layer from
 55 conduits in the wings or control surfaces of aircraft and we do not claim such use of porous surface sections.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—
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1. A fluid conduit in which the boundary layer fluid is tapped-off from regions
 65 of adverse pressure gradients through a

porous insert or inserts forming part of the wall of the conduit.

2. A fluid conduit as claimed in Claim 1 in which the porous insert consists of a sintered metal or alloy. 70

3. A fluid conduit as claimed in Claim 1 in which the porous insert consists of a ceramic mass.

4. A fluid conduit as claimed in Claim 1 in which the porous insert consists of closely packed fine mesh gauze. 75

5. A fluid conduit as claimed in any one of the preceding claims in which the porous insert forms parts of a stationary element of a rotary machine such as a
 80 rotary compressor.

6. A fluid conduit as claimed in any one of the Claims 1 to 4 in which the porous insert forms part of a rotary element of a rotary machine such as a rotary compressor. 85

7. A multi-stage axial flow compressor comprising a fluid conduit as claimed in Claim 5 in which the porous inserts are arranged in the circumferential wall of the casing between two adjacent rows of stationary blades of a high pressure stage. 90

8. A multi-stage axial flow compressor as claimed in Claim 7 in which the tapped-off zone is connected back to the main
 95 fluid conduit at a stage of lower pressure than the said high pressure stage.

9. A multi-stage axial flow compressor aggregate comprising a compressor as claimed in Claim 7 in which the tapped-off zone is connected with a stage of an associated machine, such as another compressor arranged in series flow before the tapped-off compressor. 100

10. A multi-stage axial flow compressor or compressor aggregate as claimed in Claim 8 or Claim 9 in which the tapped-off zone is connected with the zone of lower pressure through a cooler. 105

11. A multi-stage axial flow compressor or compressor aggregate as claimed in Claim 8 or Claim 9 in which the tapped-off fluid is returned with an axial flow component in front of the leading edges of a row of blades either of the rotor or
 115 of the stator.

12. A multi-stage axial flow compressor comprising a fluid conduit as claimed in Claim 6 in which the porous inserts are arranged in the rotor drum between two
 120 adjacent rows of rotor blades of a high pressure stage.

13. A multi-stage axial flow compressor as claimed in Claim 6 in which the tapped-off zones are connected with a central axial
 125 bore of the rotor.

14. A multi-stage axial flow compressor or compressor aggregate as claimed in Claim 11, Claim 12 or Claim 13, in which the tapped-off fluid is returned through
 130

apertures in the trailing edge of a hollow stator or rotor blade.

15. A radial flow compressor comprising a fluid conduit as claimed in Claim 5 in which the porous inserts are arranged opposite that radial part of rotor blades where the adverse gradient has its maximum range.

16. A radial flow compressor comprising a fluid conduit as claimed in Claim 5 in which the porous inserts are arranged in the walls of the vortex chamber and/or the diffuser.

17. A radial flow compressor comprising a fluid conduit as claimed in Claim 5 in which the porous inserts are arranged on the convex sides of the diffuser vanes near the diffuser entry.

18. A radial flow compressor or compressor aggregate as claimed in any one of the Claims 15 to 17 in which the tapped-off fluid is returned to a zone of equal or lower pressure, preferably with a radial and/or tangential component in the direction of the general flow, of the same or an associated compressor.

19. A cascade of stationary vanes such as a ring of stator blades of an axial flow compressor including between themselves fluid conduits as claimed in any one of the Claims 1 to 4 in which the porous inserts are arranged at the convex side of the vanes at and/or before the crest of the curve in the direction of flow.

20. A cascade of rotary blades such as a row of rotor blades of an axial flow compressor including between themselves

fluid conduits as claimed in any one of the Claims 1 to 4 in which the porous inserts are arranged on the convex side of the blades at and/or before the crest of the curve in the direction of rotation.

21. A fluid conduit as claimed in Claim 1 substantially as described.

22. A multi-stage axial flow compressor as claimed in Claim 7 substantially as described with reference to Fig. 1 of the drawings left with the provisional specification.

23. A radial flow compressor as claimed in Claim 15 substantially as described with reference to Fig. 2 of the drawings left with the provisional specification.

24. A cascade of vanes substantially as described with reference to Fig. 4 of the drawings left with the provisional specification.

25. A diffuser vane of an axial flow compressor substantially as described with reference to Fig. 3 of the drawings left with the provisional specification.

26. A blade of a multi-stage axial flow compressor as claimed in Claim 11, substantially as described with reference to Fig. 5 of the drawings left with the provisional specification.

27. A blade of a multi-stage axial flow compressor as claimed in Claim 11, substantially as described with reference to Fig. 6 of the drawings left with the provisional specification.

Dated this 5th day of November, 1947.

L. B. SHUFFREY,
Agent for the Applicants.

British

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169.4

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Cheshire et al

FINAL SPECIFICATION

GB-949-03

SHEETS
SHEET 1

Boundary Layer Control

*copy
order
230/
128*

[This drawing is a reproduction of the Original on a reduced scale.]

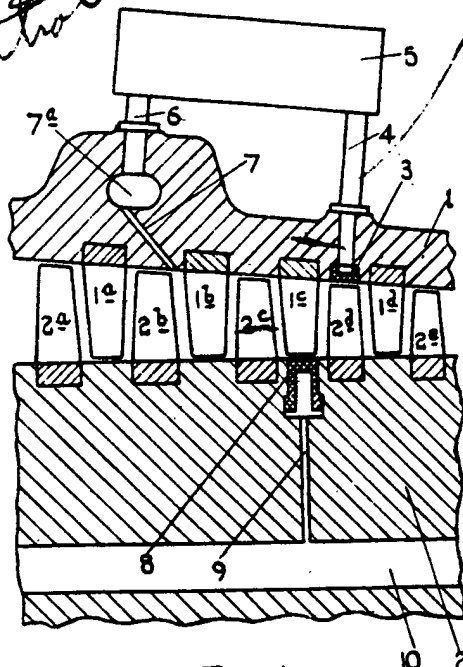


FIG. 1.

SINTERED METAL (M. ALLOY),
CERAMIC MASS,
OR CLOSE PACKED MESH+ METAL CHANNEL

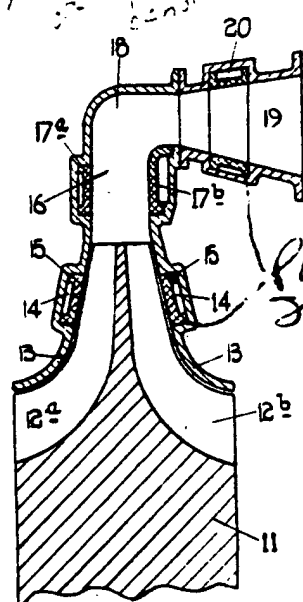


FIG. 2.

*Porous
INSERT*

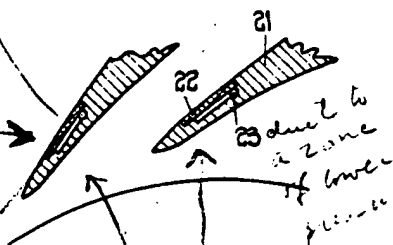


FIG. 3.

*diffusion
channel*

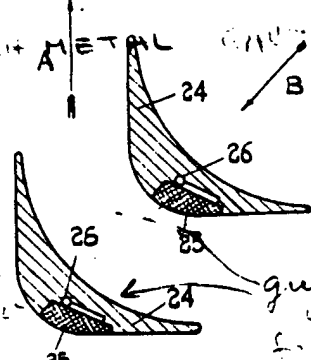


FIG. 4.

*guide ring
or
flange*

415/914
415/169.4

[This Drawing is a reproduction of the Original on a reduced scale.]

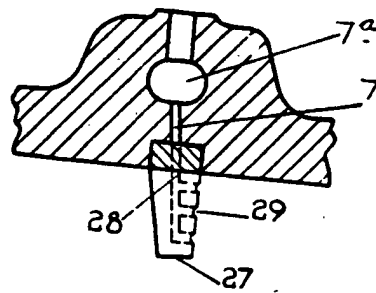


FIG. 5.

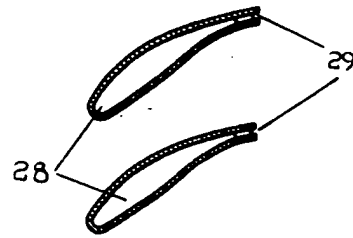


FIG. 6.